THE FLOW-STABILIZED Z-PINCH EXPERIMENT: ZAP

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ICC 2000

22-24 February 2000

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Outline

- Pure Z-Pinch and Conventional Stabilization Techniques
- Shear Flow Stabilization of the Z-Pinch
- ZaP Concept and Experimental Design
- Experimental Results Showing a Period of Low MHD Mode Activity
- Comparison to Theory
- Future Plans

Stabilization of the Pure Z-Pinch

The pure z-pinch (no applied axial fields) described by

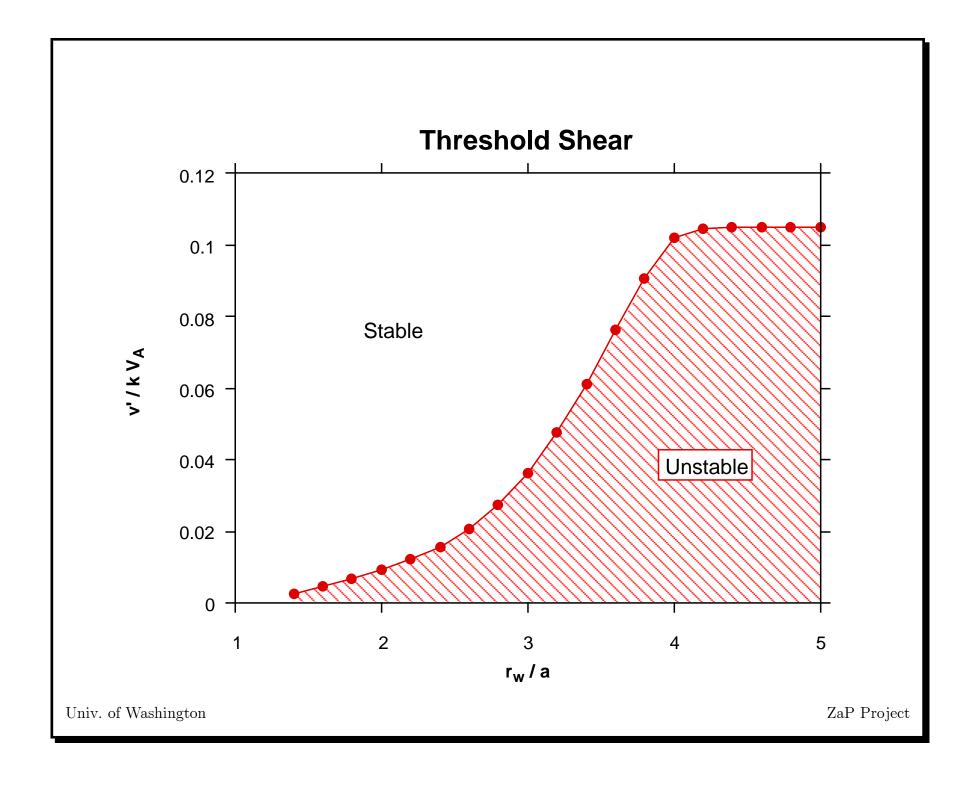
$$\frac{B_{\theta}}{\mu_{o}r}\frac{d(rB_{\theta})}{dr} + \frac{dp}{dr} = 0.$$

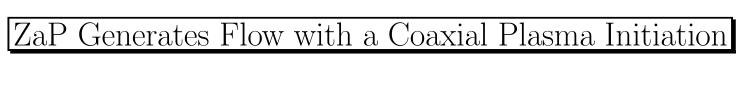
is classically unstable to m=0 sausage and m=1 kink modes.

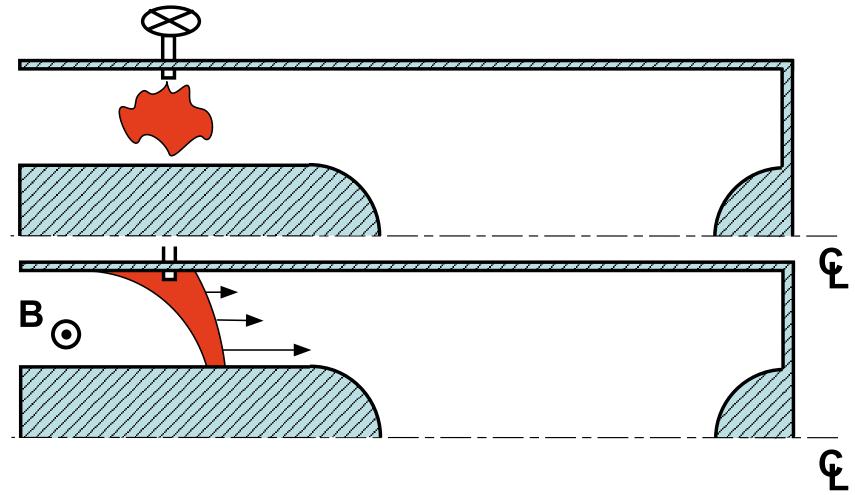
Conventional techniques to provide stability have drawbacks.

- $Profile\ Control \rightarrow Stabilizes$ the sausage mode, but not the kink mode.
- Close-Fitting Wall \rightarrow Must be very close, $r_{wall}/a < 1.2$.
- Axial Magnetic Field→ Limits the plasma current (and pressure) according to Kruskal-Shafranov limit.

However, linear stability analysis suggests that a sheared flow can stabilize the sausage and kink modes in a pure Z-pinch.

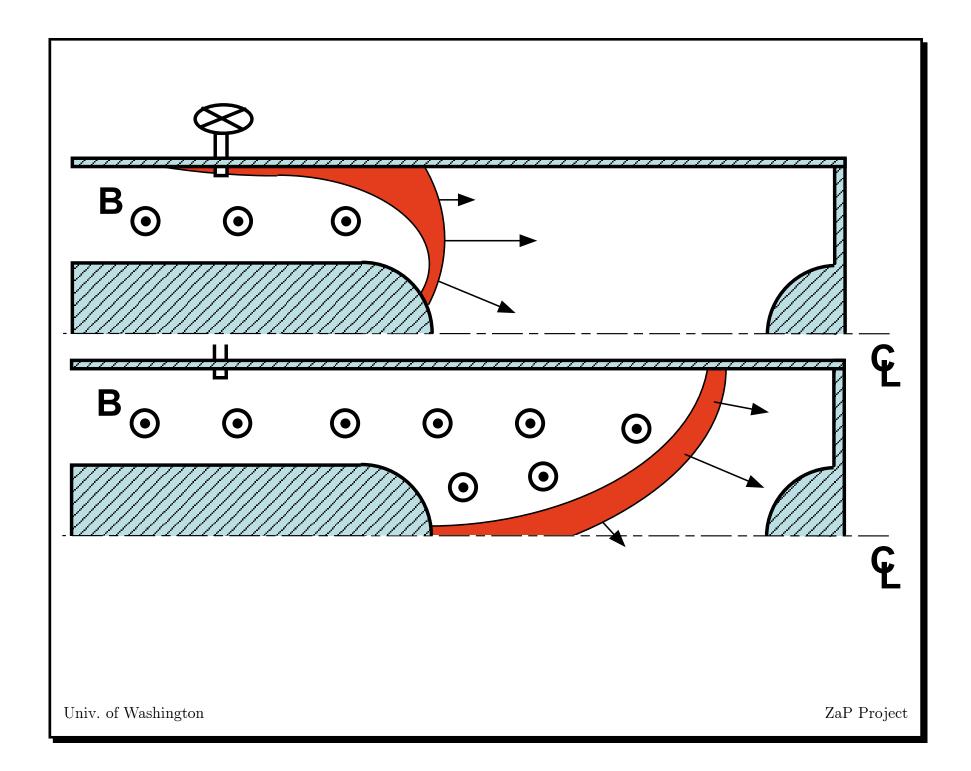


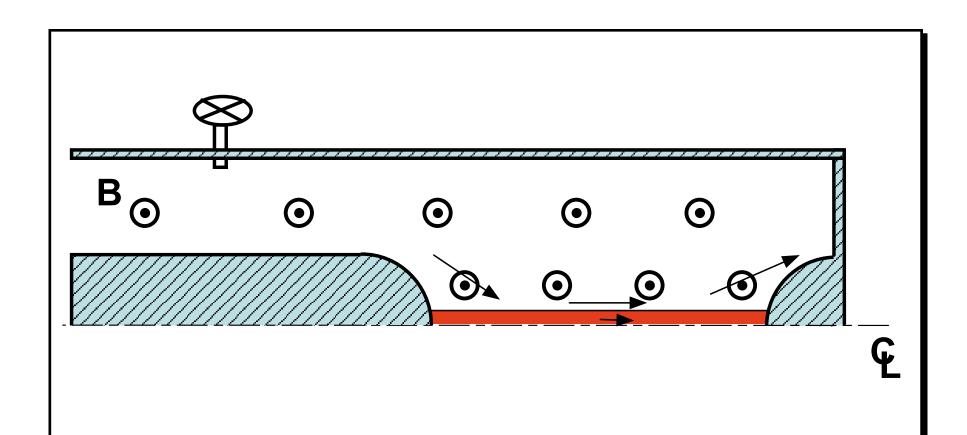




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ZaP Project

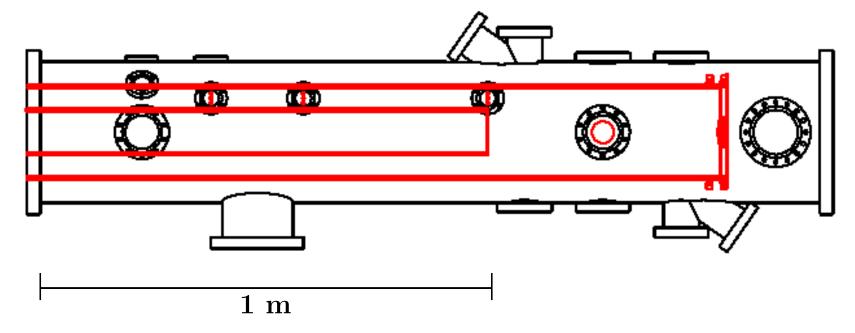




The ZaP Experiment

The primary objective of the ZaP project is to experimentally determine the connection between plasma flow and plasma stability.

ZaP uses an unmagnetized Marshall gun to initiate a flowing Z-pinch in the assembly region.



Present ZaP Operating Parameters

Entity	Design Value
Gun Length	100 cm
Inner Electrode O.D.	10 cm
Outer Electrode I.D.	20 cm
Capacitor Bank Energy	30 kJ
Charge Voltage	9 kV
Peak Current	250 kA
Plasma Column Length	$50 \mathrm{cm}$
Density	10^{17} cm^{-3}
Plasma Diameter	2 cm
Gas Injection	-75 cm
Inner Electrode End	$-25~\mathrm{cm}$
Return Electrode End	$25~\mathrm{cm}$

ZaP Diagnostics Enable Determination of Flow and Stability

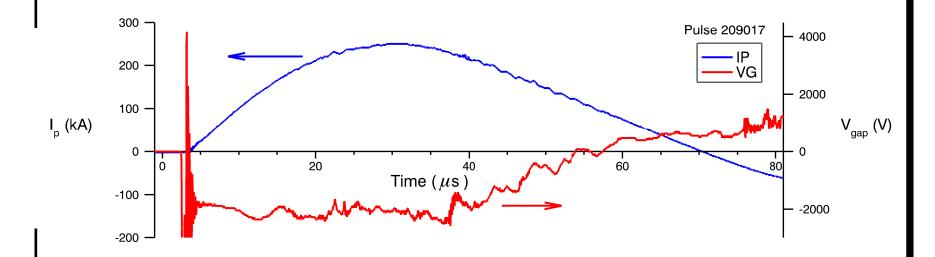
The ZaP diagnostics seek to measure plasma parameters, gross mode activity, and plasma flow.

- Axial and azimuthal arrays of surface-mounted magnetic field probes
- Visible HeNe interferometer
- Fast framing camera with optical filters
- High resolution spectrometer with CCD and PMT output options.

Most of the data that will be presented is acquired at the axial midpoint of the plasma pinch z = 0cm.

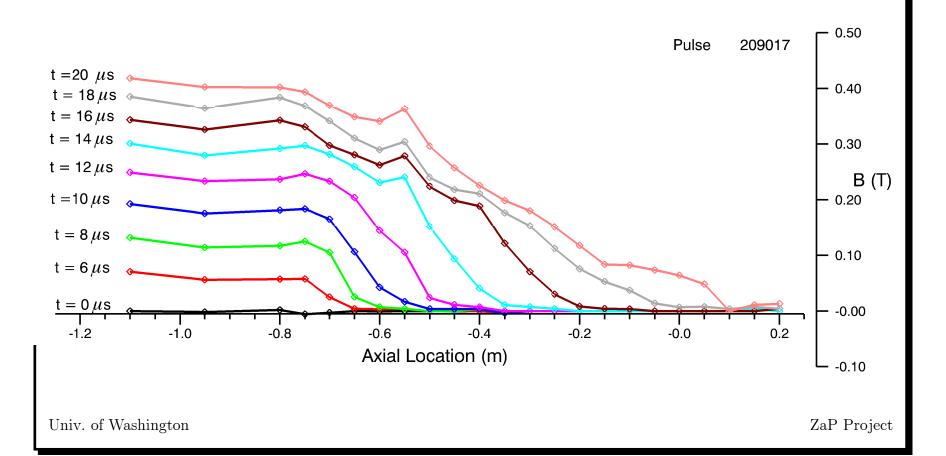
Plasma Current and Voltage Evolution

The current has a quarter cycle time of $\sim 25\mu sec$. The voltage evolution does not behave like a simple RLC circuit because the accelerating and pinching plasma provides a time-varying inductance.



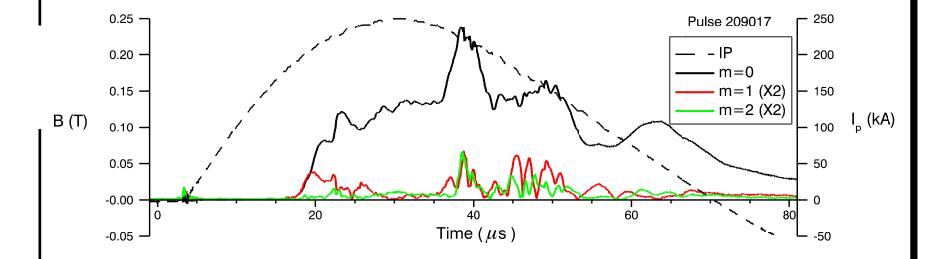
Magnetic Field Measurements Show Plasma Acceleration

Magnetic probe data shows the azimuthal magnetic field as a function of axial location, $B_{\theta}(z)$, for times during the initial plasma acceleration.



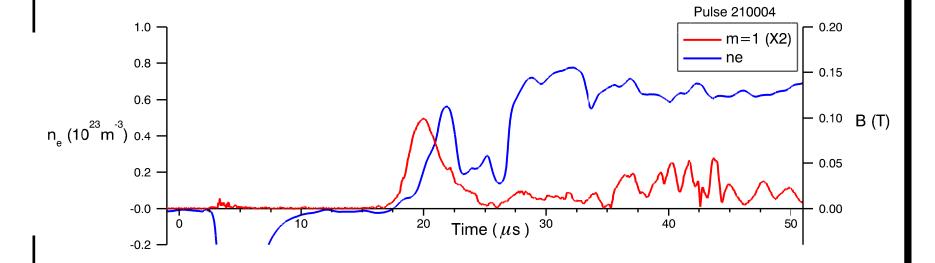
Magnetic Mode Activity Diminishes after Pinch Forms

The evolution of the magnetic mode activity is measured at z = 0. The mode activity is reduced to a few percent for $\approx 10\mu sec$ after the pinch forms. The mode activity increases again when plasma current decays.



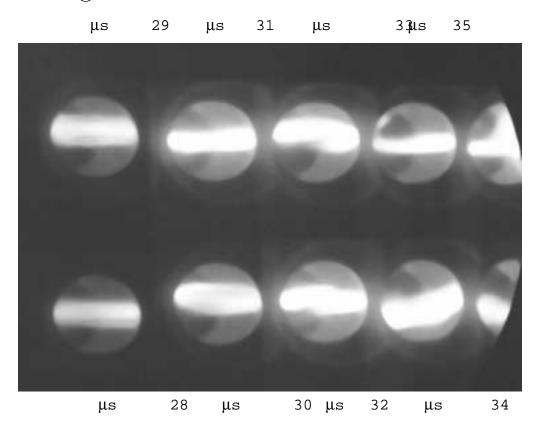
Electron Density Indicates Stationary Plasma Pinch

The electron density shows the plasmas arrival and compression at z = 0. The density appears relatively constant during the stable period.



Optical Emission Images Show a Stationary Plasma Pinch

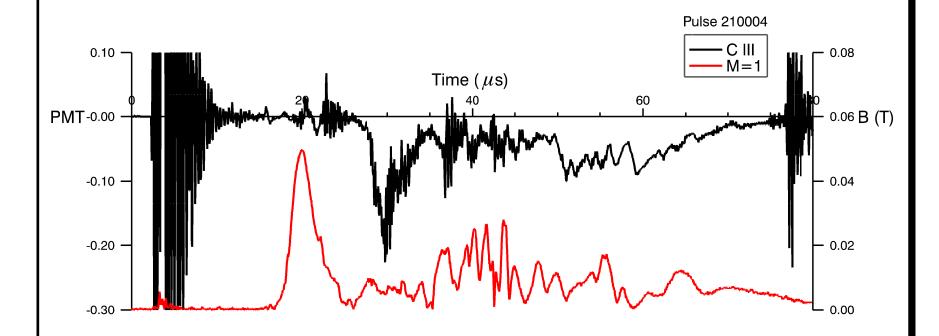
Optical emission photographs obtained with a fast framing camera show a stationary plasma pinch. The images are obtained using an H_{α} filter and a Bremsstrahlung filter.



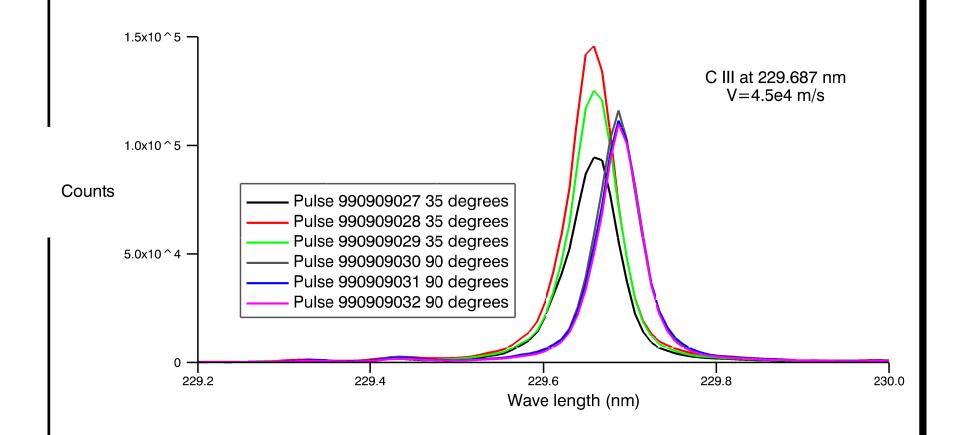
Pulse 000204018 Z=0 Brems Filter

UV C-III is Used for Spectroscopy

The presence of the C-III line correlates with the low magnetic mode activity.







Experimental Summary and Comparison to Theory

The experimental values are: $B_a = 0.9T$, $\rho_0 = 5 \times 10^{-5} kg/m^3$, $[V_A = 1.2 \times 10^5 m/s] \ a = 1.5 cm$, and $\langle V \rangle = 4.5 \times 10^4 m/s$.

This gives a theoretical growth time for a static z-pinch of

$$\tau_{qrowth} = (kV_A)^{-1} = 40 nsec$$

for $ka = \pi$.

The flow stabilization theory requires $V' > 0.1kV_A$.

$$V' \approx \frac{V}{a} > 0.1kV_A$$

gives

$$V > 3.8 \times 10^4 m/s$$

which is satisfied by the experimentally measured flow velocity.

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Future Plans

- Double capacitor bank energy to 70kJ, then add second capacitor bank to increase total bank energy to 140kJ with a quarter cycle time of $100\mu sec$.
- Add a second interferometry beam.
- Build insertable magnetic probes to measure $B_{\theta}(r)$ in the pinch. [This will also give p(r) directly and $T_e + T_i$ from the density data.]
- Install an intensified, gated imaging spectrometer to provide spatial and temporal resolution of the Doppler shift axial velocity measurements.
- Install a holographic interferometer to obtain spatially resolved density data.

Summary

- Linear stability analysis shows that flow stabilizes the gross instabilities of the Z-pinch.
- The ZaP experiment was built to experimentally verify flow stabilization.
- The ZaP project is producing z-pinch plasmas that exhibit gross stability for 250 times the growth times for static pinches.
- As the bank energy and current duration are increased we expect to continue testing the sheared flow stabilization theory.
- A flow-stabilized z-pinch has important implications for a simple reactor design, space propulsion, and other configurations.